Tropical Cyclone Formation/Structure/Motion Studies

Patrick A. Harr
Department of Meteorology
Naval Postgraduate School
Monterey, CA 93943-5114
Telephone: (831) 656-3787 FAX: (831) 656-3061 email: paharr@nps.edu

Award No: N0001405WR20200

LONG-TERM GOALS

The long-term goals are to understand how variabilities in the large-scale atmospheric environment influence tropical cyclone track, structure, and intensity characteristics and define how these influences differ between developing, mature, and decaying tropical cyclones. During the initial stages of tropical cyclone development, structure and track characteristics can exhibit large variabilities that decrease potential predictability. Because decaying tropical cyclones often transition to fast-moving and rapidly-developing extratropical cyclones that may contain gale-, storm-, or hurricane-force winds, there is a need to improve understanding and prediction of the extratropical transition (ET) phase of a decaying tropical cyclone. The structural evolution of the transition from a tropical to extratropical circulation involves rapid changes to the wind, cloud, and precipitation patterns. Furthermore, the ET of a tropical cyclone may impact the midlatitude circulation patterns downstream. Therefore, a tropical cyclone throughout its life cycle has the potential for impacting many fleet units.

OBJECTIVES

One objective of this project is to identify the physical mechanisms in the large-scale circulation that act to initiate, maintain, and terminate periods of enhanced or reduced tropical cyclone activity over the western North Pacific. If reliable forecasts of extended periods of increased or reduced tropical cyclone activity could be made, maritime operations could be coordinated appropriately.

A second objective is to examine the impact of the ET of tropical cyclones on the large-scale midlatitude circulation. The impact is assessed in terms of the increased variability that is introduced into the midlatitude circulation by the ET event and with respect to the predictability associated with the downstream impacts of the ET. The goal is to determine which aspects of ET are least predictable by examining forecast characteristics that are most inconsistent among multiple integrations of the Navy Operational Global Atmospheric Prediction System (NOGAPS) and among members of the NOGAPS and Global Forecast System (GFS) ensemble forecast systems. Also, the structural evolution of the decaying tropical cyclone as it transitions from a tropical to extratropical cyclone is examined to identify important environment conditions associated with an ET that may impact operational forecasts of the environmental conditions related to maritime operations near an ET event.

A third objective is to define a dynamic decision model that could be applied to the sortie/no sortie decision associated with a potential tropical cyclone landfall.

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **30 SEP 2005**	2. REPORT TYPE	3. DATES COVERED **00-00-2005 to 00-00-2005**

4. TITLE AND SUBTITLE **Tropical Cyclone Formation/Structure/Motion Studies**	5a. CONTRACT NUMBER
	5b. GRANT NUMBER
	5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER
	5e. TASK NUMBER
	5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **Naval Postgraduate School,Department of Meteorology,Monterey,CA,93943**	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR'S ACRONYM(S)
	11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES
code 1 only

14. ABSTRACT
The long-term goals are to understand how variabilities in the large-scale atmospheric environment influence tropical cyclone track, structure, and intensity characteristics and define how these influences differ between developing, mature, and decaying tropical cyclones. During the initial stages of tropical cyclone development, structure and track characteristics can exhibit large variabilities that decrease potential predictability. Because decaying tropical cyclones often transition to fast-moving and rapidly-developing extratropical cyclones that may contain gale-, storm-, or hurricane-force winds, there is a need to improve understanding and prediction of the extratropical transition (ET) phase of a decaying tropical cyclone. The structural evolution of the transition from a tropical to extratropical circulation involves rapid changes to the wind, cloud, and precipitation patterns. Furthermore, the ET of a tropical cyclone may impact the midlatitude circulation patterns downstream. Therefore, a tropical cyclone throughout its life cycle has the potential for impacting many fleet units.

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**Same as Report (SAR)**	**8**	

APPROACH

To explain the variation in temporal clustering due to primary large-scale, slowly-varying atmospheric circulation patterns, a hierarchical framework of global-scale intraseasonal circulations and regional-scale monsoon trough variability is defined. Previous research has identified a potential role of the variability in the large-scale circulation over the Southern Hemisphere on the tropical western North Pacific monsoon trough environment during June-October. The Southern Hemisphere circulation patterns are examined in the context of the Antarctic Oscillation (AAO). The AAO is identified by a circulation index that represents the meridional variability in the subtropical and polar jet streams over the Southern Hemisphere. The variability in the Southern Hemisphere global-scale circulation, which is identified by the AAO index, is then linked to variability in the tropical western North Pacific monsoon trough. A 15-25 day variation in the monsoon trough during June-October is identified by an index derived from a singular-value decomposition (SVD) of the 850 hPa wind anomalies and outgoing longwave radiation (OLR) anomalies over the western North Pacific. Relationships between the two modes are examined to identify factors that explain variability in tropical cyclone activity/inactivity over the tropical western North Pacific.

The impact of other global-scale intraseasonal circulations such as the Madden-Julian Oscillation is also examined in relation to the variability in the monsoon over the maritime continent during December-February. An SVD representation of the Madden-Julian Oscillation (MJO) is used as a framework for a composite analysis of the MJO impact on the patterns of monsoon-related rainfall.

Ensemble prediction systems (EPS) from several operational global model forecasts of ET cases are examined to identify the evolution of forecast uncertainty downstream and upstream of an ET event. It is hypothesized that when ET is forecast to occur at the extended forecast ranges, ensemble members exhibit large variability in terms of the type of ET and its impact on the general flow patterns of the midlatitude large-scale circulations. As the time of the initiation of ET nears, the ensemble members should begin to cluster around a specific ET scenario. At the time when the ensemble members are observed to group in relatively few clusters, then there is increased confidence in the forecasts of the important weather events associated with ET that may have widespread impacts on the midlatitude circulation. The clustering of ensemble member is identified in an objective manner by applying an empirical orthogonal function (EOF) analysis to the 500 hPa height fields from the EPS. The EOF analysis is applied to forecasts that verify at the time of the ET, which is identified to be 12 h after the final best-track time. The principal components (PCs) associated with the leading EOF patterns and assigned to each ensemble member are clustered utilizing a fuzzy cluster algorithm. The process is applied to a sequence of forecast intervals from 144 h to 24 h prior to the ET time. The number of clusters is identified as the time to the ET decreases. Individual cluster forecast sequences are examined to identify the impact of the ET on the forecasts of the downstream midlatitude circulations.

Data from polar-orbiting satellites are examined to provide a representation of the structural evolution of the thermal, wind, and precipitation fields during an ET event. A representative ET case was chosen in a pilot study of the structural changes in thermal and precipitation fields during the ET. The microwave data were examined in context with operationally derived model analyses.

A Markov-based model was defined for simulation of tropical cyclone tracks to develop a dynamic decision model for tropical cyclone landfall.

WORK COMPLETED

An AAO index was defined relative to the 15-25 day variability in the monsoon trough over the western North Pacific. Representative patterns in AAO activity were identified relative to active and inactive periods in the monsoon trough. Patterns of variability in convection over the maritime continent during December-February were related to the passage of the MJO. A detailed study of the increased spread in the GFS ensemble forecasts of TY Tokage (October 2004) was conducted. The evolution of representative ET traits was defined by a repeated application of EOF and cluster analyses on forecasts that verify at the time of ET. The variability in the initial conditions was examined for each ensemble cluster to identify the initial perturbation pattern associated with the cluster. The structural evolution of the ET of TY Ma-on (September, 2004) was examined with microwave data to identify patterns of precipitation and thermal structure. A dynamic decision model was applied to simulated tropical cyclone landfalls at Norfolk, VA and Galveston, TX.

RESULTS

The monsoon trough over the western North Pacific has been found to vary between active and inactive periods of convection over a period of 15-25 days. Patterns of low-level circulation anomalies and OLR have been identified with an SVD analysis and the principal components of that analysis define an index of monsoon trough variability. The AAO index was linked to the monsoon trough index to define four basic patterns of global-scale circulation variability over the Southern Hemisphere during June-October (Burton 2005). The impact of the AAO on the monsoon trough variability occurred via Rossby-wave propagation toward the equatorial Pacific as the meridional shift in Southern Hemisphere jet streams occurred in conjunction with the AAO. As the AAO shifted from a negative to a positive state in conjunction with the start of an active monsoon trough cycle (Fig. 1), there was an associated wave pattern with an equatorial cyclonic anomaly in the Southern Hemisphere (E2 in Fig. 1) that contributed to the active monsoon trough. During the opposite transition to a negative AAO during an inactive monsoon trough (Fig. 2), there was an equatorial anticyclone (EA1 in Fig. 2) that contributed to a weak monsoon trough. Similar patterns were identified for corresponding negative to positive transitions in the AAO during the 15-25 day monsoon trough cycle.

The ensemble forecasts from the GFS during the ET of TY Tokage at 0000 UTC 19 October, 2004 exhibited a pronounced increase in standard deviation that began near the ET event and spread downstream in longitude and time (Fig. 3). The downstream increase in variability occurred in conjunction with a Rossby wave-like pattern with individual maxima in standard deviation located at the troughs of the wave pattern (Reeves 2005). A cluster analysis at 0000 UTC 19 October defined two distinct modes of ET that were incorporated in the ensemble members. The number of clusters at this time, which was 48 h prior to the ET, was reduced from five clusters at 0000 UTC 16 October, which was 120 h prior to the ET. Therefore, the ensemble system was beginning to identify a preferred ET pattern as the time to ET approached.

Analysis of microwave data from polar-orbiting satellites during the ET of TY Ma-on identified an upper-level warm structure that was located over the surface location of the tropical cyclone as ET was started. As the ET process progressed, the upper-level warm region, which was identifiable in the AMSU-A data, was displaced downstream from the low-level circulation (Stubblefield 2005).

This provided an indication that microwave data could be used to identify coherent structural evolution during the ET process that may be used to diagnose the intensity of the extratropical cyclone that results from the ET.

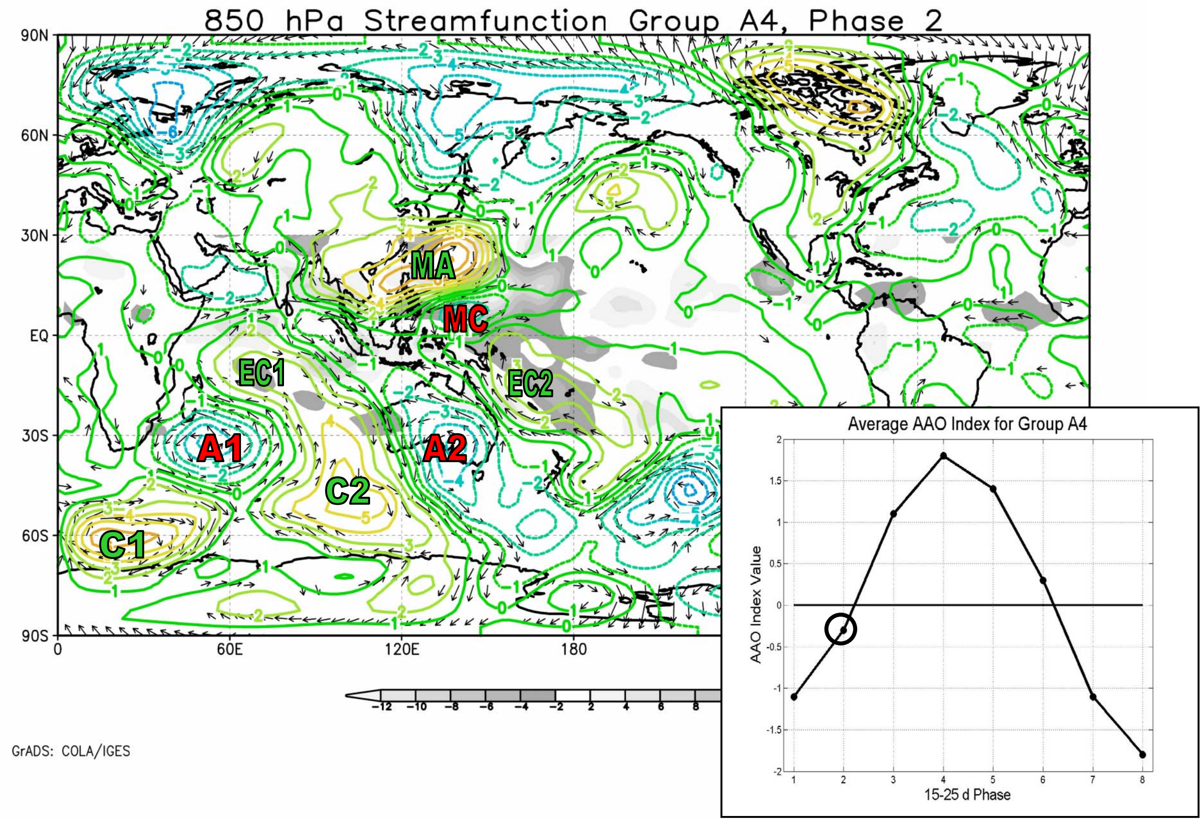

Figure 1. Streamfunction (contours, interval 10^6 m^2 s^{-1}) and 850 hPa wind anomalies (vectors) associated with the start of a shift in the AAO from a negative state to a positive state during a 15-25 day cycle in the western Pacific monsoon trough. The eight phases of the 15-25 day monsoon trough cycle are depicted in the inset such that phase 4 defines the peak of the active convection stage of the cycle. The curve defines the average AAO index associated with a shift from negative to positive 15-25 day monsoon trough cycle.

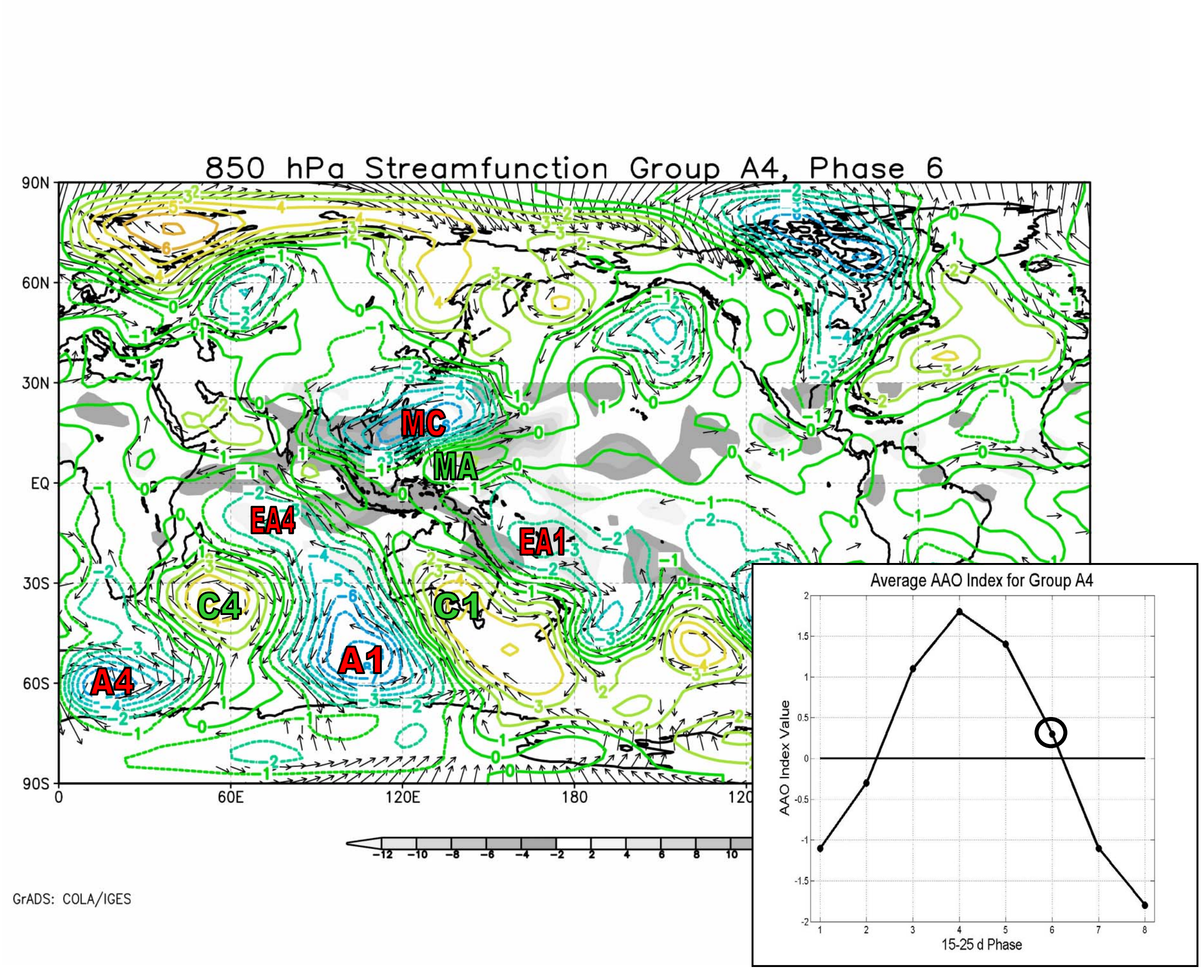

Figure 2: As in Figure 1, except for the transition from an active to inactive monsoon trough.

The variation in monsoon-related convection over the maritime continent was linked to passage of an MJO and occurrence of a southerly surge over the South China Sea (Chang et al. 2005). A type of interference pattern was identified by which combination of the two circulations impacts the variability in convection over the maritime continent.

Application of a dynamic decision model to a simulated hurricane landfall at Norfolk, VA (Regnier and Harr 2005) identified that there could be as much as an 8% savings in total expected costs if the decision process was optimized in relation to the value of forecast information, which was assumed to increase as lead time to the landfall decreased.

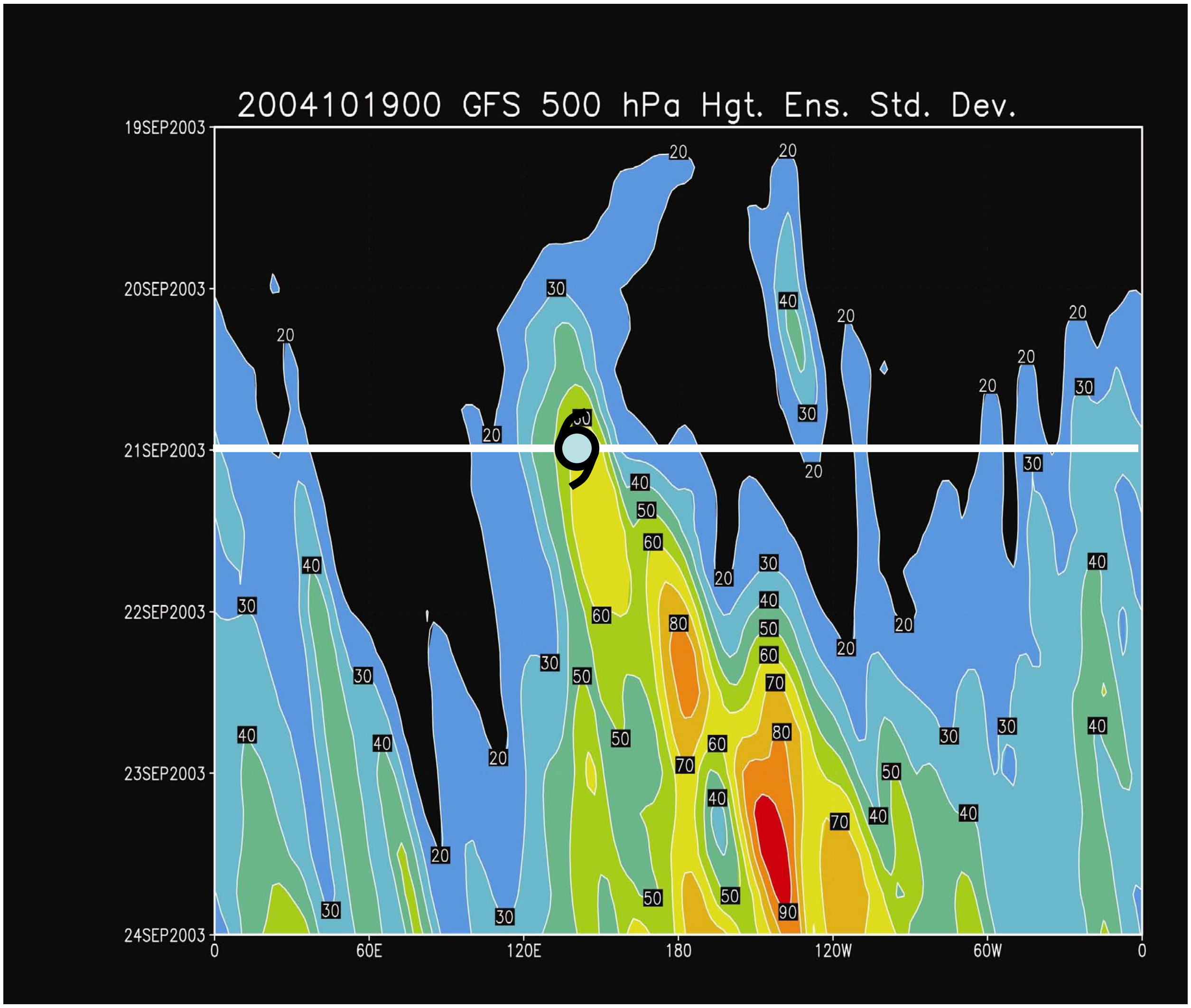

Figure 3: A Hovmoeller diagram of the 500 hPa height standard deviation in the GFS ensemble forecasts from 0000 UTC 19 October 2005 for TY Tokage. The longitude of the ET of TY Tokage is marked by the tropical cyclone symbol at 0000 UTC 21 September 2004. Time increases downward along the ordinate and longitude proceeds from west to east along the abscissa.

IMPACT/APPLICATIONS

Identification of the interactions between various modes of tropical circulation variability will lead to a statistical forecast scheme of extended periods of tropical cyclone activity/inactivity. If reliable forecasts of extended periods of inactivity (i.e., at least 20 days with no tropical cyclones) could be made, maritime operations could be coordinated to take advantage of the period of reduced threat from tropical cyclones.

As characteristics and identification of the predictability associated with operational forecast model characteristics with respect to ET become identified, guidance to operational forecasters will be available such that increased value from numerical products will be realized.

TRANSITIONS

It is anticipated that an operational forecast scheme of intraseasonal variability in tropical cyclone activity will be based on the research results from this project. An assessment of the potential for accurate forecasts with respect to ET circulations will be available to operational forecasters. Systematic examination of microwave data during the ET of tropical cyclones will lead to use of a pattern analysis by forecasters to diagnose the important structural changes during the ET process.

SUMMARY

During the next year, results from the examination of the interaction between modes of tropical circulation variability will provide a sound forecast system for assessment of tropical cyclone activity that may be expected over ranges between 10-25 days. Finally, the assessment of the capability of each operational numerical model to predict various components of ET will provide operational forecasters with information to efficiently assess model guidance.

REFERENCES

Burton, K., 2005: Influence of Antarctic Oscillation on Intraseasonal Variability of Large-scale Circulations over the Western North Pacific. M.S. Thesis, Naval Postgraduate School, 114 pp.

Chang, C. -P., P. A. Harr, and H.-J. Chen, 2005: Synoptic disturbances over the equatorial South China Sea and western Maritime Continent during boreal winter. Mon*. Wea. Rev*., **103**, 489-503.

Reeves, J., 2005:Predictability Associated with the Downstream Impacts of the Extratropical Transition of Tropical Cyclones. M.S. Thesis, Naval Postgraduate School, 115 pp.

Regnier, E., and P. A. Harr, 2005: A dynamic decision model applied to hurricane landfall. *Wea.and Forecasting*. (submitted).

Stubblefield, C., 2005: Microwave Estimates of the Extratropical Transition Process. M.S.Thesis,Naval Postgraduate School, 86 pp.